

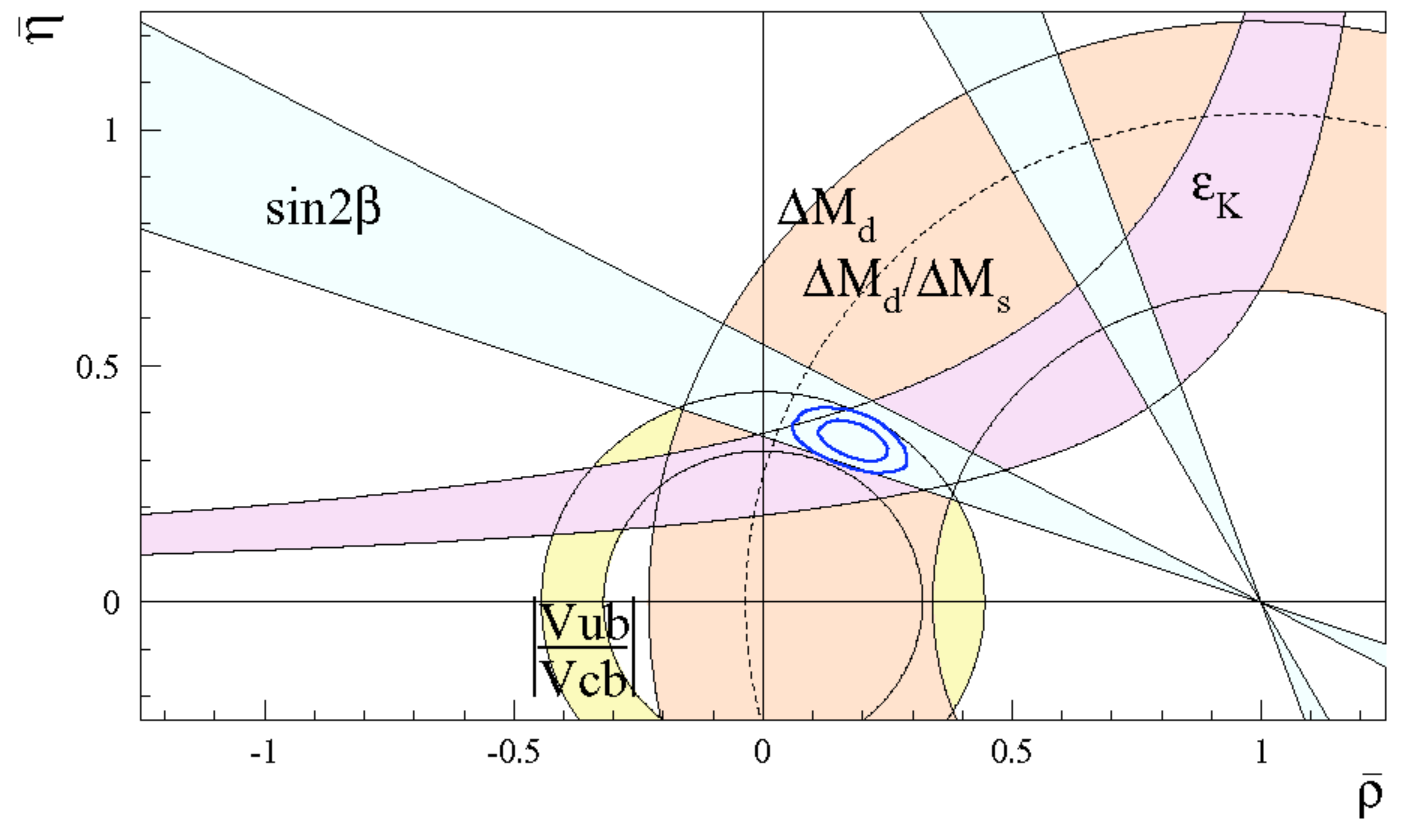
Lattice Gauge Theory at Fermilab

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Additional material at:
<http://lqcd.fnal.gov>.

DoE Annual Review
Fermilab
March 24, 2004

Lattice QCD calculations have become essential to some of the central goals of the HEP experimental program.



M. Ciuchini hep-ph/0307195.

E. g., potential to improve the ρ – η plane is huge.
Of the five best constraints:

K K bar mixing **currently dominated by lattice uncertainties.**

B B bar **currently dominated by lattice uncertainties.**

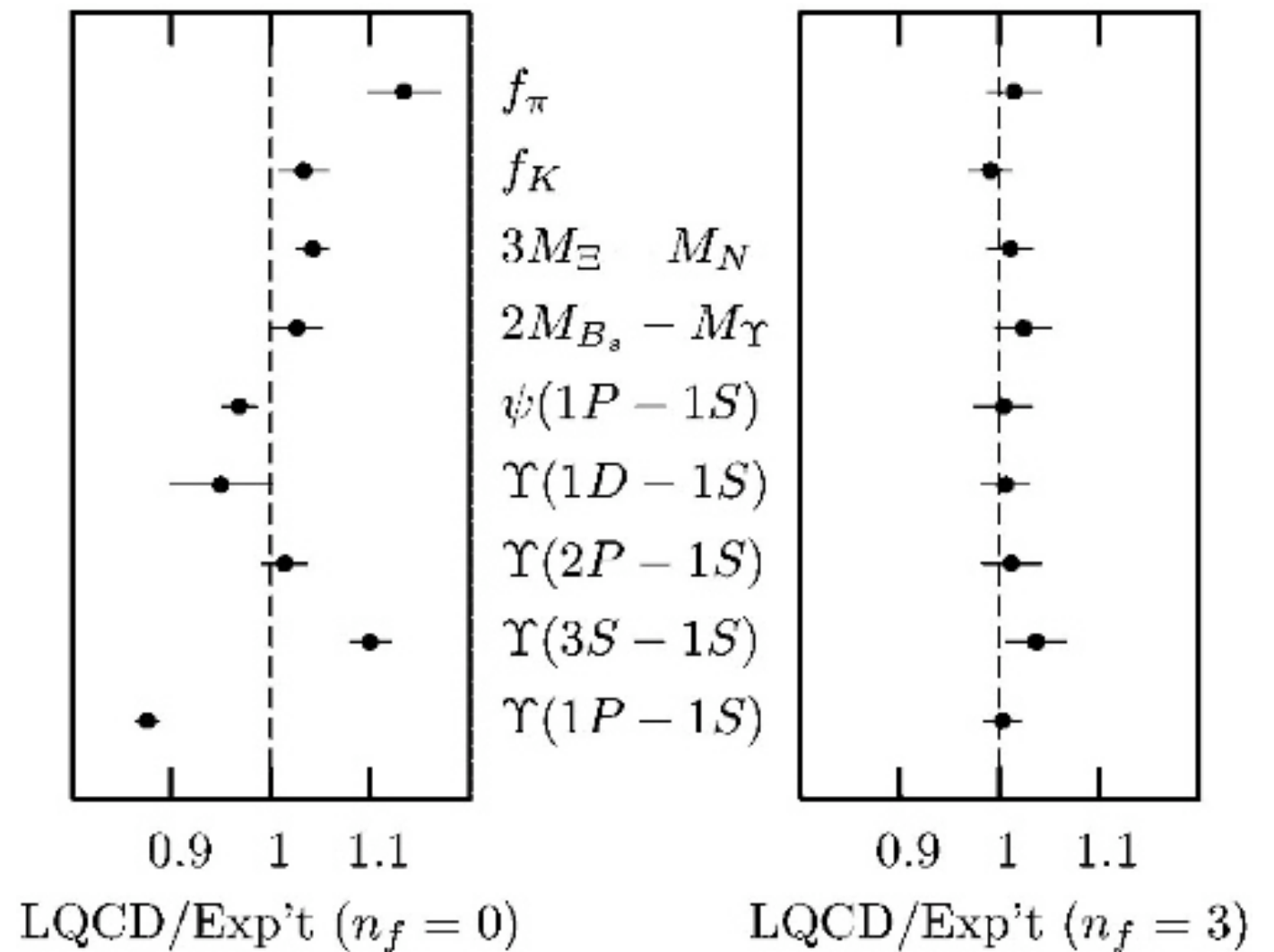
Bs Bs bar **will be dominated by lattice uncertainties.**

V_{ub} : ($B \rightarrow \pi l \nu$) **will be dominated by lattice uncertainties.**

$\sin 2\beta$: **dominated by experimental uncertainty.**

Recent big progress with unquenched improved staggered fermions.

Several groups compared their simplest calculations. 10% disagreement quenched → few per cent agreement unquenched.



C.T.H. Davies *et al.*,
Phys.Rev.Lett.92:022001,2004, hep-lat/0304004.

What about slightly more complicated quantities?
 Do other light quark methods agree?

arXiv:hep-lat/0304004 v1 7 Apr 2003

Lattice window on strong force

A long-awaited breakthrough has been made in lattice quantum chromodynamics — a means of calculating the effect of the strong force between sub-atomic particles that could, ultimately, unveil new physics.

C. T. H. Davies,² E. Follana,¹ A. Gray,¹ G. P. Lepage,² Q. Mason,²
M. Nobes,³ J. Shigemitsu,⁴ H. D. Trottier,³ and M. Wingate⁴
(HPQCD and UKQCD Collaborations)

M. Di Piero,¹² A. El-Khadra,¹³ A. S. Kronfeld,¹⁴ P. B. M.
(HPQCD and Fermilab Lattice

(Dated: 31 March 20

PACS numbers: 11.15.Ha, 12.38.Aw, 12.38.Gd

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Quantum chromodynamics is the elegant but notoriously intractable theory of the strong interactions. Recent advances in numerical computer simulation are beginning to reveal, in impressive detail, what the theory predicts.

By to pry loose one of the three valence quarks in a proton. Before going much further than the nucleus, the person takes a 1 ft or 10" rod, such as one enough work to create a new quark-antiquark pair (they promptly appear, choose new partners, and you find a meson in one hand).

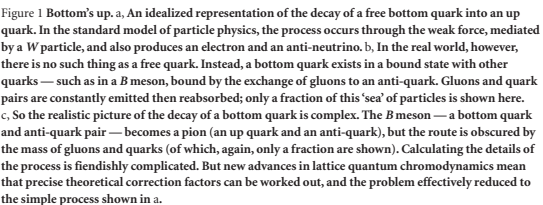
and a proton or neutron in the other. No isolated quarks! At distances an order of magnitude smaller than 1 fm, or, equivalently, at interaction energies or momenta transferred in the nn - np range of ~ 1 GeV, the energy-dependent QCD analog of the fine-structure constant is effectively $\alpha_s \approx 1$. In the limited regime, perturbation theory works, and pencil-and-paper methods succeed. But for the larger distances and softer interactions, where confinement is the dominating process, it is effectively impossible and we must resort to computerized numerical simulations.

In 1971, Kenneth Wilson at Cornell University first introduced a version of QCD in a discrete quark-line lattice (see the left panel of figure 11 and, with pencil and paper, used it to provide a plausible but not rigorous argument for color confinement. Wilson argued that, in a coarse-grained lattice, the potential energy of separating a quark and an anti-quark must rise linearly with distance. In 1978 at Brookhaven National Laboratory, Michael Creutz, Lucien Montanucci and Claudio Rebbi demonstrated the feasibility of the first meaningful numerical simulations with Wilson's formulation on a Cornell Data Corp 7600 computer.² Shortly thereafter, Creutz obtained numerical results for the confinement potential that supported Wilson's conclusion. That success launched a new branch of computational physics, called at its inception lattice QCD.³ The right panel of figure 11 shows a modern lattice QCD result for the quark-antiquark potential.⁴

For two decades after Gauss's pioneering 1805 calculations, refinements in algebra, linear and computing power brought steadily gains in precision and consistency. But only in the past four years have powerful algorithms and theoretical improvements advanced us into the age of high-precision linear QCD—a basis for solving key hadronic quantities.

By the standards of the strong interaction, "high precision" means 1 or 2%. The impact of two new precision experiments showed the strong interactions. Determining any features of the weak interactions of neutrinos. For example, the Columbia-Schrybner-National (CSND) experiment—requiring correcting measured weak decay rates for strong interaction effects—was lost. The uncertainties in our knowledge of such fundamental parameters limits the precision with which the standard model of its elementary particles can be tested and probed for new realms of physics.

Barclay DeToro is a professor of music at the University of
California, Los Angeles. Steven Gellman is a professor of physics
at the University of California, Berkeley.



would be no matter in the Universe today. So how did that asymmetry arise?

If heavy particles that existed in the early Universe decayed preferentially into matter over antimatter, that could have created the matter excess. In the standard model, two types of quark, bottom and strange, do decay asymmetrically. But this effect alone is far too small to account for the asymmetry. However, there are many theories that predict the existence of other, massive particles that could readily produce the asymmetry. And

because of the connection between asymmetry and mass, these theories also address other puzzles, such as why electrons are almost 10,000 times lighter than bottom quarks.

Searching for evidence of these particles can be done directly or indirectly: powerful accelerators, reaching ever higher energies, could create these mysterious particles; or there is the precision approach of looking for subtle deviations in the properties of known particles, influenced by the unknown. If

These are examples of some of the “golden quantities of lattice QCD: single stable meson processes. Other examples:

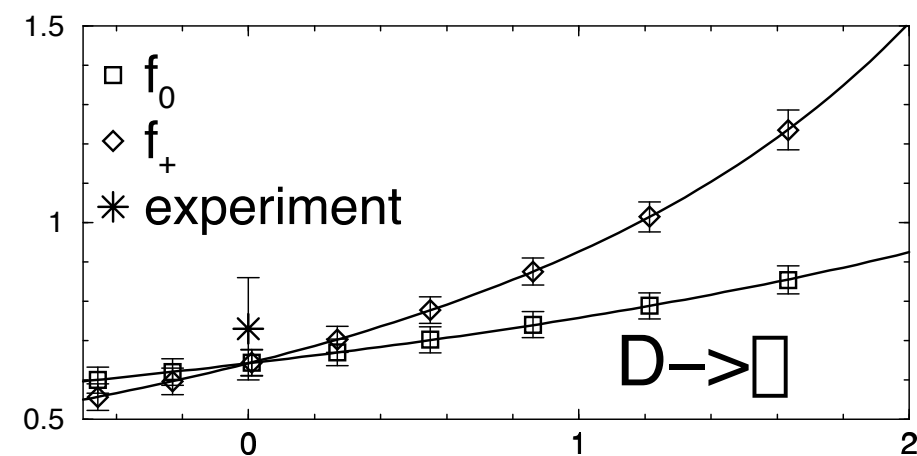
KK bar, BB bar, and $BsBs$ bar mixing,
 $B \rightarrow \pi l \nu$, $B \rightarrow D l \nu$,
 $D \rightarrow \pi l \nu$, $D \rightarrow K l \nu$,
 $K \rightarrow \pi l \nu$.

Example of current work : $D \rightarrow \pi l \nu$.

Cleo-c will measure $f_D / D \rightarrow \pi l \nu$ and $f_{D_S} / D \rightarrow K l \nu$ to 2%. Interesting and rare CKM independent test of lattice heavy-light methods.

One-loop perturbative calculations (in progress) will leave 8-10% perturbative uncertainties.
Goal: make all other uncertainty significantly smaller than this.

$$f_+^{DK} = 0.75, f_+^{D\pi} = 0.63. \text{ (Preliminary!)}$$



M. Okamoto et al., at Lattice 2003, hep-lat/0309107.

Fermilab's lattice work is part of DoE's national effort to establish computational infrastructure for lattice QCD initiated under the SciDAC program.

US "Lattice QCD Executive Committee" (Sugar, chair, Brower, Christ, Creutz, Mackenzie, Negele, Rebbi, Sharpe, Watson) reports to DoE on plans and needs of US lattice QCD.

\$2M/year, three-year SciDAC grant will probably be extended through '05.

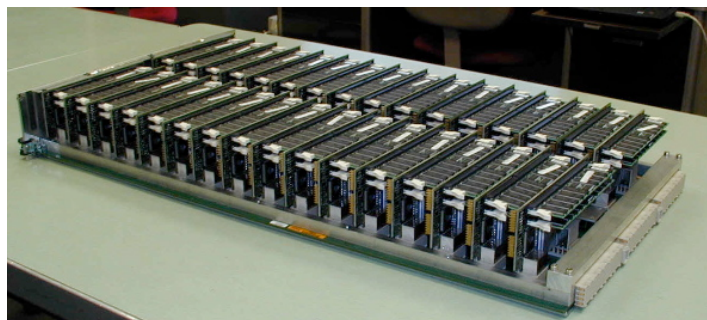
Two major components of national program:

Large, tightly coupled
clusters (Fermilab/JLab):



Nonlocal communication
through switch, well
understood user environment.

QCDOC
(Columbia/BNL):



Local, highly scalable
communication.

Fermilab lattice cluster effort
is led by Don Holmgren.

The clusters are
currently housed in the
New Muon Lab.



The 172 node Pentium 4 cluster.
~100 GFlops.



<http://lqcd.fnal.gov>

lqcd.fnal.gov PBS Cluster Status

Sat Mar 13 19:06:16 CST 2004

The screenshot displays the PBS Cluster Status page for lqcd.fnal.gov. At the top, there's a navigation bar with icons for back, home, search, and other functions. The main content area shows a grid of job status for various nodes. The grid is organized into rows and columns, with each cell containing a node ID and a status code. Below the grid, there's a summary bar showing the number of free, down, offline, reserve, job-exclusive, and job-sharing nodes, along with a usage percentage. To the right of the summary bar, there's a 'Temperature' indicator showing 'WARM'. Below the summary bar, there's a 'Job List' table showing details for various jobs, including Job Id, Job Name, User, Time Used, Time Req, Status, Queue, and Nodes.

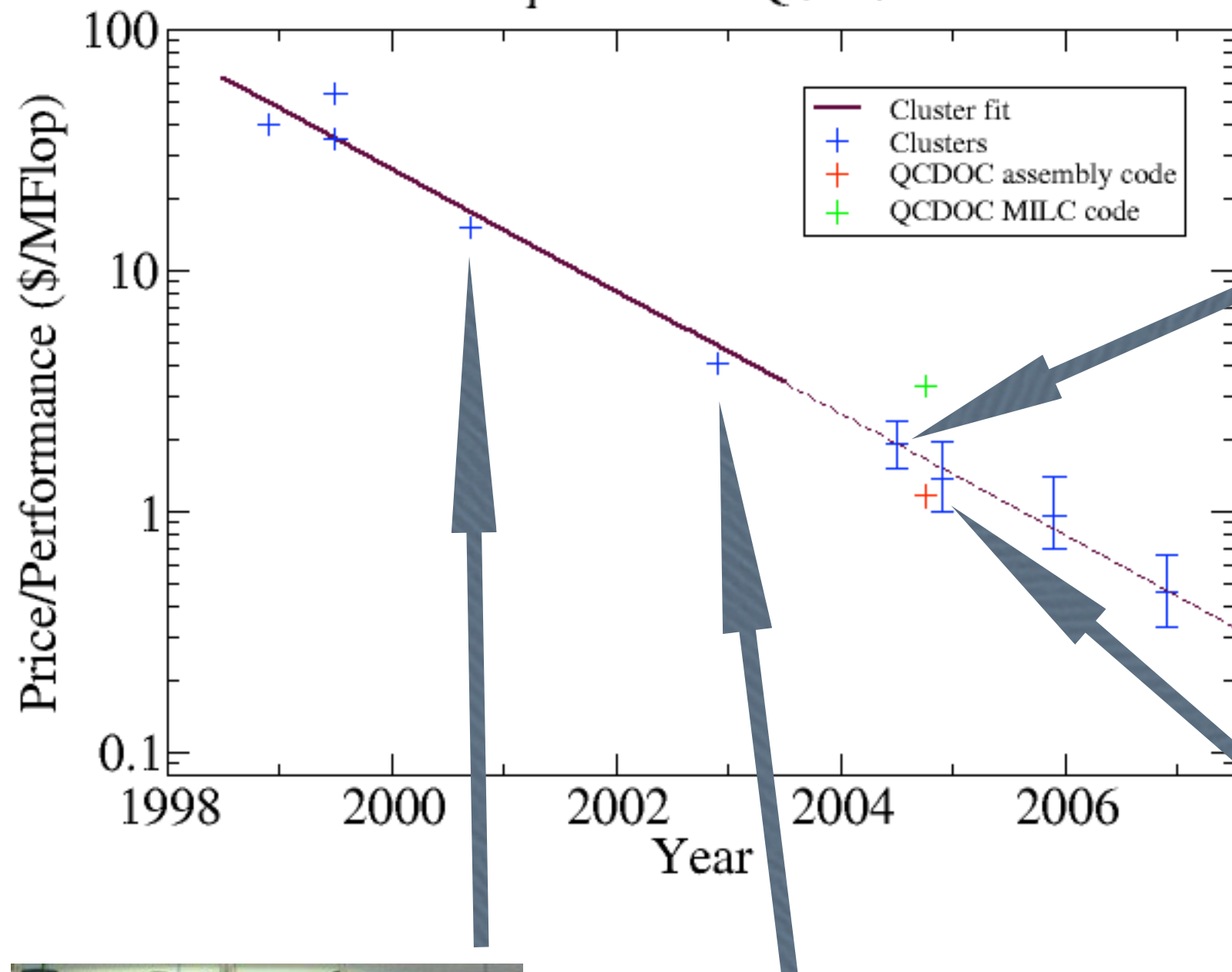
Job Id	Job Name	User	Time Used	Time Req	Status	Queue	Nodes
1000	b-0-Sap	Masataka Okamoto		24:00	Queued	workq	4
1001	b-0-Sao	Masataka Okamoto		24:00	Queued	workq	4
1002	b-0-Saf	Masataka Okamoto		24:00	Queued	workq	4
1003	b-0-Sag	Masataka Okamoto		24:00	Queued	workq	4
1020	pQaen	Jim Simone		09:45	Queued	workq	16
1027	b-0-Sat1	Masataka Okamoto		24:00	Queued	workq	4
1032	pQaen	Jim Simone	08:43	09:45	Running	workq	16
1033	pQaen	Jim Simone	06:14	09:45	Running	workq	16
1034	pQaen	Jim Simone	06:09	09:45	Running	workq	16
1035	pQaen	Jim Simone	06:06	09:45	Running	workq	16
1038	pQaen	Jim Simone		09:45	Queued	workq	16
1039	pQaen	Jim Simone	02:29	09:45	Running	workq	16
1040	pQaen	Jim Simone	02:15	09:45	Running	workq	16

Job list a mixture of perturbation
theory and valence calculation
and analysis;
1 node, 4 node, 16 node jobs, etc.



Cluster Performance Trends

"Asqtad" Lattice QCD Code



2004:

128 P₄ singles,
reuse Myrinet switch.
Incremental cost:
\$_I/MF.

256 node, P₄ singles?
Infiniband switch.

2005: 512 node,
\$_IM, 1 TF.

2006: 1024 node,
\$1.5 M, 3 TF
(or double).



At February, 2004 HEPAP meeting, Bob Sugar, in a well-received talk, reported the “absolute minimum support required for health of field”.

Our answer: \$3M/year:

	2004	2005	2006	...
QCDOC	\$5M, 5 TF		\$0	
HEP Clusters	\$1 M, 1 TF		\$3 M, 6TF?	

DoE-HEP response: \$2M/year.

Discussions with Nuclear and ASCR are ensuing.